24th International Young Physicists’ Tournament

Team of Belarus

Iran Tehran
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Ministry of Education
Republic of Belarus

Kayson Belarus
Team of Belarus presents task

Breaking spaghetti
Breaking spaghetti

Find the conditions under which dry spaghetti falling on a hard floor does not break.
How do spaghetti lands?

Tin-soldier position

Prone

Hesitating
Rain of spaghetti soldiers
Drag

\[ \vec{F} = -\frac{1}{2} C_d \rho \vec{v}^2 S \]

Where S is reference area (for long cylinder it is its basement area), \( \vec{v} \) is velocity, \( \rho \) is air density, \( C_d \) is drag coefficient (for long cylinder it is 0.82)
Drag influence

![Graph showing the influence of drag over time (t_s) vs. distance (h_m).]
Work limiter

\[ mg = -\vec{F} \]

\[ \nu_{\text{max}} = \sqrt{\frac{2mg}{\rho S C_d}} \]

\[ \nu_{\text{max}} \approx 59.5 \text{ m/s} \]
The Claws
Low-tech

Breaking point
Claws output:

- Young’s modulus $E = 0.59 \pm 0.02$ GPa
- Critical stress $\sigma_{\text{crit}} = 31 \pm 0.5$ MPa
- Critical relative stretch $\varepsilon_{\text{crit}} = 5.25 \pm 0.05$ %
Critical curvature

\[ 2\pi(R + d) - 2\pi\left(R + \frac{1}{2}d\right) \]
\[ \frac{\cdot 100\% = \varepsilon_{\text{crit}}}{2\pi\left(R + \frac{1}{2}d\right)} \]
R vs. diameter
Frequency of breaking depending on velocity

Average error of frequency: 0.15
Estimation of forces

\[ F > \frac{mv}{t_{\text{max}}} \]

where time of impact \( t_{\text{max}} < 0.001 \) s, \( m = 4.5 \times 10^{-5} \) kg, \( v \approx 6 \) m/s

\[ F \approx 5.67 \cdot 10^{-1} \, N \]

\[ mg \approx 4.5 \cdot 10^{-4} \, N \]

\[ F \gg mg \]
Frequency depending on length

Average error of frequency: 0.15; of length: 0.2 cm
...and diameter

Average error of frequency: 0.15; of diameter: 0.01 mm
Length of broken part depending on diameter

Average error of length: 0.2 cm
... on original length of spaghetti

Average error of length: 0.2 cm
War is over...
... for this unknown soldier
Spaghetti is rising in waves

\[ c = \lambda \cdot v \]

\[ c = \sqrt{\frac{E}{\rho}} \]
Measuring Young’s modulus
Hot pursuit

\[ E = 0.59 \, \text{GPa} \]

\[ \rho = 884.6 \, \text{kg/m}^3 \]

\[ c = 0.76 \, \text{km/s} \]

\[ c \cdot t_{\text{max}} = 0.76 \, \text{m} \]
Spaghetti processor unit

\[ c = 0.76 \frac{km}{s} \]

\[ \lambda = 0.02 \, m \]

\[ v = \frac{c}{\lambda} = 38 \, kHz \]
20 kHz maximum... 😞
Vibration table for spaghetti

40 kHz

Amplifier
Frequency depending on price?

Average error of frequency: 0.15
Frequency depending on humidity

Average error of frequency: 0.15
Turn the work limiter on!

Because of the higher drag coefficient and subsequently bigger reference area air resistance increases, while maximum velocity decreases.

\[ \nu = 5.6 \text{ m/s} \]
Conclusions

• If falling prone, in Earth’s atmosphere spaghetti can’t reach velocity required for breaking.
Conclusions

• If falling in tin-soldier position, spaghetti is breaking because of standing wave, and breaking occurs at a length of 1 cm from the end, which was hit.

• Spreading rate of this wave is 1.7 km/s, and estimated frequency is 84 kHz.
Conclusions

• Breaking requires certain amount of energy, this is why increasing spaghetti mass (length), we decrease required velocity.

• Forces of interaction between spaghetti and surface are 1000 times bigger, than gravity force, acting on spaghetti.
Conclusions

• Increasing diameter, we’re increasing not only mass, but also energy required for breaking, so required velocity is increasing too.
Conclusions

• Chemical ingredients have very strong influence on energy, required for breaking. Breaking of dry spaghetti requires lower speed, than usual ones. And eggs in expensive spaghetti are increasing required energy.
But:

We can discuss only energy, required for breaking of ideal spaghetti. In real life, we can say only about increasing in breaking probability, when close to predicted values.
Spaghetti strikes back
Over 3000 spaghettis were harmed while making this presentation.
Splits and random fluctuations
Starch structure
How does spaghetti break?

Layer structure